TECHNOLOGICAL INNOVATION AND PRODUCTIVITY GROWTH IN U.S. AGRICULTURE

by

YAO-CHI LU

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ABSTRACT

The growth rate for U.S. agricultural productivity through the year 2025 may decline if the past trend of support for research and extension continues into the future. However, with increased support for research and extension, three major emerging technologies--photosynthesis enhancement, bioregulators, and twinning beef cattle--may be developed and adopted by farmers before the turn of the century. Adoption of these emerging technologies will shift productivity growth to a higher growth curve. It was projected under these circumstances that the growth rate through the year 2025 may equal the historical rate.

PREFACE

This paper was prepared for presentation at the Workshop on Innovation Policy and Firm Strategy sponsored by the International Institute of Applied Systems Analysis on December 4-6, 1979, in Laxenburg, Austria. It was based on the results and methodology presented in the report--Prospects for Productivity Growth in U.S. Agriculture by Yao-Chi Lu, Philip Cline, and Leroy Quance, USDA, ESCS, Agricultural Report No. 435, September 1979.

In this paper, projections of agricultural productivity were updated and extended from the year 2000 to year 2025 and two scenarios were added to evaluate the effects of reduced funding for research and extension on agricultural productivity growth.

The author is indebted to Dr. John M. Brazzel for his encouragement in preparing this paper. Thanks are also due to Drs. Leroy Quance, Larry Summers, and Eldon Weeks for reviewing the earlier draft of this paper.

FOREWORD

This paper was prepared for presentation at the Workshop on Irrigation Policy and [illegible] sponsored by the International Institute of Applied Systems Analysis on November [illegible], 1976, in Laxenburg, Austria. It was based on the data and methodology presented in the report "Prospects for Potentially Irrigable [illegible] [illegible] by [illegible] Duncan [illegible], and [illegible] [illegible], ERS, Agricultural Economic Report No. [illegible], September 1976.

In this paper, projections of agricultural productivity were updated and extended from the year [illegible] to year 2000 and the [illegible] were added by author. The effects of reduced supplies for [illegible] and expansion on agricultural productivity [illegible].

The author is indebted to Dr. [illegible] for his encouragement in preparing this paper. Thanks are also due to Mrs. [illegible], [illegible] Summers, and Eldon [illegible] for reviewing the earlier draft of this paper.

SUMMARY AND CONCLUSIONS

This study examines historical productivity changes in U.S. agriculture, identifies forces influencing productivity changes, estimates the quantitative relationships between productivity and its sources, and simulates future productivity growth paths to the year 2025 under alternative scenarios.

The results indicate that productivity is expected to continue to grow but the rate of growth would decline if the past trend of public support for research and extension (R & E) continues into the future. Under the baseline scenario, where the real R & E expenditures are assumed to increase 3 percent per year, the rate of productivity growth would decline from 1.1 percent per year for the 1978-2000 period to 0.8 percent for the 2000-2025 period. These growth rates are considerably less than the rate during the past half-century--1.6 percent.

These results were derived from the simulation model and the following productivity growth hypothesis.

Technology is the major longrun influence on agricultural productivity growth. Generally, when an agricultural technology is introduced for commercial adoption, its initial impact on productivity is small. Only a few farmers adopt the new technology, and they cannot evaluate its profitability immediately. As the early adopters benefit, more farmers are attracted to the

technology, and productivity then grows at an expotential rate. Eventually, the growth rate declines as the technology's potential is realized, until no more growth can be achieved under the technology. Thus, productivity grows along a classical S-shaped growth curve.

However, as productivity approaches its limit to growth under a given technology, other new technologies may emerge. Emergence of a new technology breaks through the limit and shifts productivity growth to a new S-shaped curve. Historical changes in agricultural productivity verify this hypothesis.

Currently, agricultural productivity is growing along the longrun growth curve under the "science power" epoch, which began at the end of World War II. This growth curve may soon enter the stage of declinine rate of growth.

Under the baseline scenario, the R & E expenditures are assumed to increase 3 percent per year. These expenditures will likely be sufficient only to develop enough minor and "defensive" technologies to keep productivity on the current growth curve. Since no unprecedented technologies are anticipated to emerge in order to push productivity to a higher growth curve, the rate of growth will decline over time.

As current data indicate that public support for R & E has been declining, the effect of reduced funding on productivity growth is estimated under three scenarios: zero R & E growth,

negative R & E growth, and no R & E. Because of a lengthy lead time and long adoption processes for a new technology, the shortrun effect of reduced funding is relatively small, but the longrun effect is very significant. For example, if the R & E growth rate is reduced from 3 percent per year under the baseline scenario to zero percent per year assumed in the zero R & E growth scenario, the productivity index will be reduced only 0.7 index points in 1990, but it will be reduced 8.2 index points in 2025. If public support for R & E reduces 2 percent per year (the negative R & E growth scenario), the rate of productivity growth would be further reduced.

Under the no R & E scenario, the effect of reduced funding is dramatized by cutting off all R & E expenditures starting in 1980. Under this pessimistic scenario, productivity would not plummet immediately because of the residual effects of previous investments in R & E. But it would drop rapidly, reaching a minimum in 1993. Then productivity would increase gradually due to an increased level of educational attainment of farmers.

The rates of productivity growth under the above scenarios are considerably less than the historical rate of 1.6 percent per year for the past 50 years. To sustain the historical growth rate, R & E expenditures must be increased to accelerate the development of new technologies and to facilitate their adoption by farmers. Increases in research funds make it likely that more technologies

will become available for adoption. Thus, we assume that new, unprecedented technological developments will occur under the high R & E scenario and shift productivity growth to a new S-shaped curve. Under this scenario, R & E expenditures are assumed to increase at 7 percent per year, and unprecedented technologies--twinning in beef cattle, bioregulators, and photosynthesis enhancement--are assumed to become available for commercial adoption. Under these assumptions, the impact of emerging technologies would shift productivity to a new growth curve and push the rate of productivity growth to 1.3 percent per year from 1978 to 2000 and to 1.6 percent from 2000 to 2025.

TECHNOLOGICAL INNOVATION AND PRODUCTIVITY GROWTH IN U.S. AGRICULTURE

Yao-Chi Lu

INTRODUCTION

A possible declining rate of agricultural productivity growth is one of the most important issues in U.S. agriculture today. In his recent speech before the Agricultural Research Institute on October 17, 1979, in Washington, D.C., Anson R. Bertrand (1979), Director of Science and Education, U.S. Department of Agriculture, indicated that the plateauing of productivity is one of the great problems facing American agriculture today.

After two and a half decades of accelerated growth, the rate of productivity growth in U.S. agriculture began to slow down in the late sixties. From 1939 to 1965, total factor productivity, as measured by output per unit of all inputs, increased 2.1 percent annually, and labor productivity grew 6.1 percent. However, from 1965 to 1970, total factor productivity increased only 0.4 percent annually and labor productivity rose 5.3 percent (U.S. Department of Agriculture 1978). Although the rate of productivity growth increased since 1970 (1.7 percent for the total factor productivity and 5.6 percent for labor productivity from 1970 to 1978), the declining productivity growth rate in the late sixties has alarmed many people. Some fear that the limit to agricultural productivity growth has been reached.

While the rate of agricultural productivity growth may be declining, demand for food, especially export demand, is increasing. At the 1976 National Academy of Sciences' (1976) Bicentennial Symposium on "Science, A Resources for Human Kind," Moeen Queshi of the International Finance Corporation estimated that the developing countries' 2.8 billion population will reach at least 4.8 billion by the turn of the century, whereas the population of the developed countries will increase from 1.2 billion to 1.5 billion. To feed this growing world population, even at current low nutritional levels, annual world food-grain production must increase 1.8 percent annually from the current 1.3 billion metric tons to about 2.0 billion metri tons by 2000. If nutritional gains are to be made in developing countries, annual food-grain production will have to reach about 3.0 billion metric tons, i.e., 3.5 percent increase annually.

What can we do to close this apparent gap between the production and demand for food? While we have little control over the demand for food, especially export demand, we have some control over the production of food. With limited resources, the best way to increase food production is through increased productivity. Then how can we increase productivity? To answer this question we need to examine the sources of productivity change.

The purposes of this paper are to examine historical changes in agricultural productivity, to identify factors which affect

productivity change, to establish quantitative relationships between productivity and its sources, and to simulate future productivity growth paths to the year 2025 under alternative scenarios.

TECHNOLOGY AND PRODUCTIVITY: HISTORICAL PERSPECTIVE

Technology is generally recognized as one of the most important forces behind productivity growth. A new technoloyg, when adopted by farmers and incorporated into production processes, will enable farmers to produce the same output with less quantity of one or more inputs or more output with the same inputs. Many changes in productivity can be traced to changes in technologies.

Generally, when an agricultural technology is introduced for commercial adoption, its initial impact on productivity is small. Only a few farmers adopt the new technology, and they cannot evaluate its profitability immediately. As the early adopters benefit, more farmers are attracted to the technology, and productivity then grows at an exponential rate. Eventually, the growth rate declines as the technology's potential is realized, until no more growth can be achieved under that technology. Thus, productivity grows along a classical S-shaped growth curve.

However, as productivity approaches its limit under a given state of technology, other new technologies may emerge. Emergence of a new technology breaks through the earlier limit and shifts productivity growth to a new S-shaped growth curve.

Thus, whether or not limits to agricultural productivity growth exist, then, depends on whether or not our scientists can continue to produce new technologies that farmers will adopt.

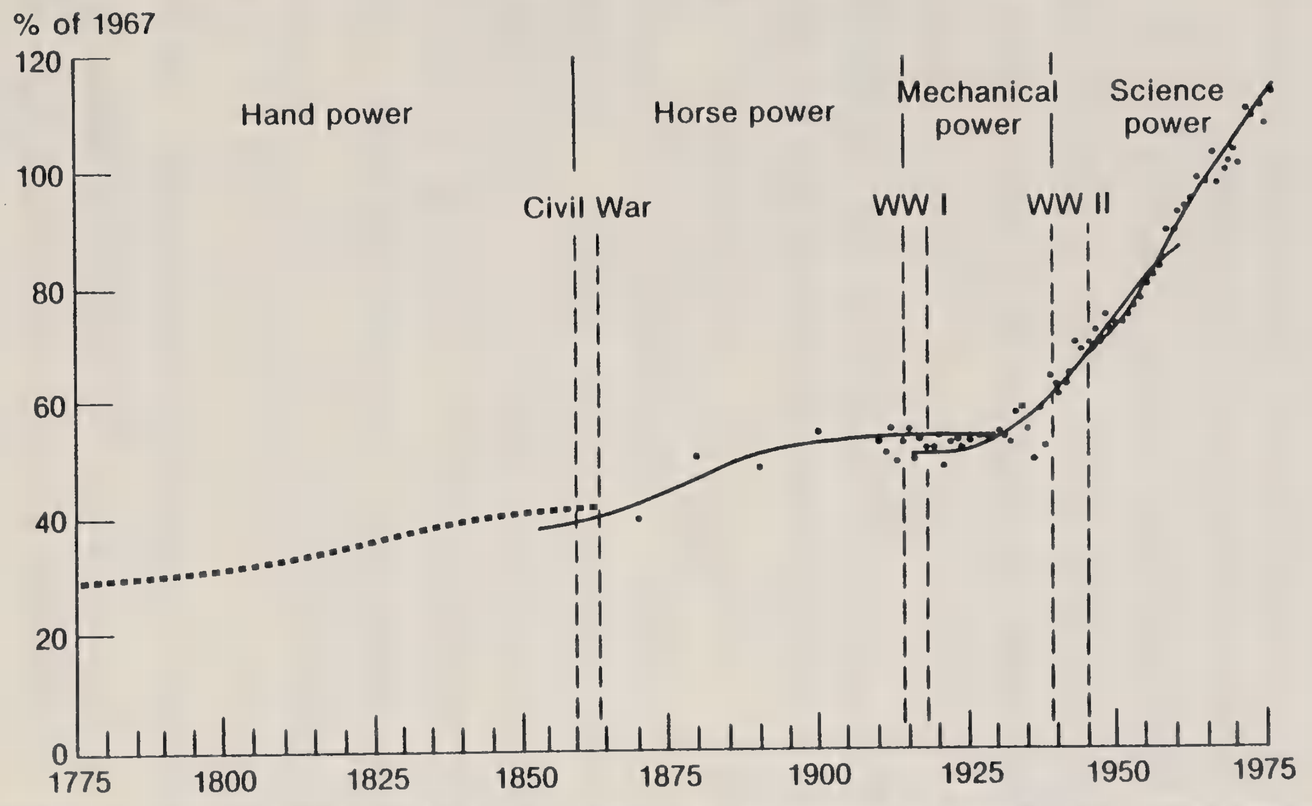
Let's use this hypothesis to explain productivity growth in U.S. agriculture for the past 200 years. Modifying an analysis by Rasmussen (1976), who divided these 200 years into three periods, we divide them into four periods according to the major sources of technological change: the American Revolution to the Civil War (hand power), the Civil War to World War I (horse power), World War I to World War II (mechanical power), and World War II to the present (science power). We identify an S-shaped growth curve for each period and view the productivity growth curve for the past 200 years as containing a series of shorter, but successive, S-shaped growth curves (fig. 1).

The American Revolution to the Civil War (Hand Power)

During this first period of American agriculture, technology was dominated by hand power. After the American Revolution, leaders such as George Washington and Thomas Jefferson looked for better implements and more efficient farming methods. They invented and adopted many improved farming practices; mixed fertilizers; and hand-powered tools and machinery such as cotton gins, cast iron plows, and mechanical reapers. Productivity increased gradually. Although lacking any measure of agricultural productivity during this period, we conclude that it grew very slowly in the late 1700's

Figure 1

U.S. Agricultural Productivity Growth During the Past 200 Years



and early 1800's and leveld off about 1830 when the limits to hand power were approached (the dotted line in fig. 1).

The Civil War to World War I (Horse Power)

Toward the end of the hand-powered epoch, many horse-drawn machines, including reapers, grain drills, corn shellers, hay-bailing presses, and cultivators of various types, were invented. These new machines cost more than labor, so farmers lacked incentive to switch. But the Civil War stimulated change from hand to horse power and thrust American agriculture into its first technological revolution (Rasmuseen 1976). A war-induced labor shortage, high demand for food and fiber, and high food prices induced farmers to adopt labor-saving horse-drawn machines. Farm programs and policies during this period were implemented to generate new knowledge which was disseminated to farmers. The U.S. Department of Agriculture, which was established in 1862, and land-grant colleges in each State taught farmers new farming practices and encouraged their adoption. The Hatch Act of 1887 established agricultural experiment stations in each State to generate new technologies. The Smith-Lever Act of 1914 created and charged the Cooperative Extension Service with disseminating knowledge about new technologies. Nationwide, county agents worked closely with farmers, teaching them about new machines and practices. Productivity accelerated after the Civil War until about 1880 and then tapered off toward the beginning of World War I as the potential of horse power was approached.

World War I to World War II (Mechanical Power)

The first practical self-propelled gasoline tractor, the forerunner of the John Deere tractors, was built by John Froelich in 1892. Internal combustion engine tractors were not widely adopted, however, until World War I. During this war, high farm prices and high wages relative to machinery prices caused rapid conversion from horse power to mechanical power, heralding the beginning of the second agricultural revolution. But the post-World War I agricultural, and then general, depression delayed an upsurge in productivity growth until after 1935. Increasing demand for food and fiber, fostered by the general economic recovery and war in Europe, accelerated mechanization of U.S. agriculture. Transition from horse power to mechanical power was virtually completed by World War II. But, unlike previous epochs, productivity growth accelerated rather than leveling off because of a continuous flow of other technologies, such as chemical fertilizers, insecticides, hybrid corn varieties, and improved breeds of livestock, into agricultural production.

World War II to the Present (Science Power)

Mechanization is only one cause of the phenomenal growth in agricultural productivity since World War I. Genetic, chemical, and mechanical engineering research developed many new technologies. Farmers increased crop yields through irrigation; lime and chemical fertilizers and insecticides; widespread use of legumes, such as

rotators, and other conservation practices; and adoption of improved varieties, such as hybrid corn. They adopted improved breeds, practiced articifical insemination of livestock, and increased livestock feeding efficiency. Each new technology shifted the productivity growth curve upward before it could reach the growth limits of the existing technology. Further, public policies, designed to provide price and income stability, and rapidly developing agricultural transportation, processing, and distribution significantly reduced risks involved in agricultural enterprises.

We have chosen to label the period since World War II a "science power" epoch in recognition of the complementary relationships between continually improving farm mechanization and advances in scientific knowledge in such areas as chemistry, biology, and genetics. One of the most significant impacts of science power is the emergence of knowledge as a resource, thus further reducing the likelihood of any absolute limit to growth in agricultural productivity.

PRODUCTION AND DISSEMINATION OF TECHNOLOGY

Productivity growth thus results from the interactions of many factors: farm policies and programs, weather, relative prices of production factors, and technology. Government farm policies and programs can work for or against productivity increases. Farm programs such as acreage retirement, target prices, and storage programs may reduce uncertainty and thereby increase productivity.

Some Government regulations, such as feedlot runoff controls and bans on the use of DDT and DES, may reduce productivity.

Weather not only directly affects shortrun productivity due to fluctuating yields from year to year and longrun productivity due to weather cycles, it can also influence adoption of new technologies. A farmer in a region with relatively stable precipitation and temperature will be more willing to adopt a new technology than a farmer operating with relatively unstable weather conditions, as the former can more easily assess the costs and benefits of the new technique.

The most important factor contributing to longrun productivity growth is technology. However, technological advance does not occur automatically. Investments in research and development are required to generate new knowledge. New knowledge may be applied by farmers directly or embodied in capital or intermediate inputs, such as pesticides.

New knowledge generated by research and development must be disseminated to, and adopted by, farmers to affect agricultural productivity. To a large extent, the rate of diffusion of a new technology is subject to profitability, degree of uncertainty, and capital requirements (Mansfield 1966, p. 123).

Profitability is by far the most important determinant of the rate of diffusion. Griliches' (1958) study indicates that hybrid corn diffused more rapidly in areas where it was more profitable

than in areas where it was less so. The profitability of a new technology depends upon relative prices and productivity--that is, the prices of outputs relative to the prices of inputs, the prices of new inputs relative to the prices of old inputs, and the productivity of the new technology relative to the productivity of the old technology.

Historically, relative prices have played the most important role in determining the rate of diffusion. As indicated earlier, many horse-drawn machines were invented before the Civil War but were not adopted because they were expensive relative to labor. The outbreak of the Civil War changed these relative prices and stimulated the adoption of horse-drawn machines. Relative prices played the same role in the adoption of mechanical power during and after World War I.

Uncertainty about a new technology is another important factor in determining its diffusion. A farmer will be reluctant to adopt a new technology if he is uncertain about its payoff. The degree of uncertainty is related to the level of educational attainment of farmers and to extension activities. Extension institutions are charged to conduct programs to disseminate technical information to farmers. Increasing education and training enable farmers to better absorb, understand, and evaluate information about new products, new inputs, and new processes disseminated by USDA, extension agents, farm journals, the news media, and seed, agricul-

tural chemical, farm machinery, and equipment companies. Therefore, increasing farmers' education and increasing extension activities will reduce uncertainty about a new technology.

Because many new technologies take the form of physical capital inputs (such as tractors) and are diffused through investments in successive generations, or "vintages" of capital goods (such as four-wheel-drive tractors), farmers must invest in more capital goods to adopt a new technology. Thus, adoption also depends upon availability of credit to finance the purchase of new capital goods (Kendrick 1976, p. 6).

In his study of technological change and the rate of imitation, Mansfield (1961) concludes that the rate of diffusion of a new technology is inversely related to the size of capital investment required for its adoption. Technologies such as new hybrid varieties, fertilizer applications, or insecticides that can be tried on a small scale without committing a large capital investment are generally adopted more rapidaly than grain combines or four-wheel-drive tractors which require a large capital investment.

AGRICULTURAL PRODUCTIVITY SIMULATION MODEL

As indicated, to sustain U.S. productivity growth, we must continually invest in research and extension (R & E) to produce new technologies that will feed into the agricultural production system. Is current support for agricultural R & E programs adequate? If not, how much more should we invest?

First, we need to estimate relationships between productivity growth and public R & E expenditures and other sources of growth. As many factors influence productivity growth, we cannot include all relevant variables in the agricultural productivity simulation model. Only the most important, observable, and measurable variables influencing productivity growth are included. We omit farm programs and relative prices, although important, because we have not been able to separate the effect of prices from the impact of technological change. And attempts to measure the impact of farm programs on agricultural productivity have not been successful, primarily because of measurement and data problems. We also exclude private research expenditures for lack of data. Thus, our study attributes changes in agricultural productivity to production-oriented public agricultural R & E expenditures, the educational level of farmers, and weather.

Based on the above observations, the productivity growth model is specified as

$$(1)\quad P_t = \prod_{i=0}^{n} R_{t-i}^{\beta_i} E_t^{\beta_{n+1}} e^{\beta_{n+2} W_t}$$

where

P_t = the value of the aggregate productivity index for U.S. agriculture in year t,

R_{t-i} = the lagged values of production-oriented R & E expenditures aiming directly at increasing agricultural production, 1/

E_t = the value of an index of educational attainment of farmers in the current period,

W_t = the value of a U.S. weather index in the current period,

n = the length of lag measured in years,

β = the coefficient.

Equation (1) indicates that the level of productivity in the current year is a function of the current educational level of farmers, weather conditions, and a distributed lag function of R & E expenditures. It is hypothesized that the form of the distributed lag weights follows an inverted U shape.

To estimate the parameters, equation (1) was transformed to the logarithmic form. Durbin's (1969) two-stage procedure and Almond's (1965) polynomial lag method were employed to fit the equation to the time series data for the U.S. agriculture. 2/ The results are as follows:

1/ Non-production oriented R & E expenditures such as rural development, food and nutrition, and agricultural marketing were originally included as a variable in the model, but because the coefficient of the variable was not statistically significant, that variable was eliminated.

2/ For the sources of data, see Lu, Cline, and Quance (1979).

$$P_t = R_t^{.0009} R_{t-1}^{.0017} R_{t-2}^{.0024} R_{t-3}^{.0029} R_{t-4}^{.0033} R_{t-5}^{.0036}$$

$$\cdot R_{t-6}^{.0037} R_{t-7}^{.0037} R_{t-8}^{.0036} R_{t-9}^{.0033} R_{t-10}^{.0029}$$

$$\cdot R_{t-11}^{.0024} R_{t-12}^{.0017} R_{t-13}^{.0009} E_t^{.7851} e^{.0020 W_t}$$

Results indicate that a 1-percent increase in public R & E expenditures in a specific year will increase productivity gradually for the first few years, reach its peak impact within 6 to 7 years by increasing agricultural productivity by 0.0037 percent each year, then decline gradually for the following 6 years at the end of which time its impact is negligible. The total increase in productivity over the 13-year period is 0.037 percent. This total impact seems small; yet it is significant. For example, the agricultural production-oriented R & E expenditures in 1972 were $377 million (in 1958 constant dollars); 1 percent of R & E expenditures in 1972 was thus $3.8 million. The dollar value of increased agricultural productivity due to the $3.8 million would have totaled about $13 million over its 13-year impact period. But to be comparable with present costs, the future returns would have to be discounted.

We also estimated that a 1-percent increase in the education index in any given year will increase productivity 0.78 percent. Consider the year 1970 as an example. The average number of years of schooling for farm operators, laborers, and foremen was 9.12, and the estimated education index was 157.2 An index point of 1.0

equals about 0.7 month of schooling. Thus, a 1-percent increase in the education index equals about 1 month of education (0.7 x 1.572). Therefore, if farmers' overall level of education had been raised by 1 month in 1970, net farm output would have increased about $267 million (1.0 index point equals approximately $343 million in 1958 dollars).

Agricultural productivity depends heavily on nature. During 1900-1972, weather variations caused productivity to rise or fall below its normal growth level more than 2.2 points in 1 out of 3 years (on the average). Should weather be 1 percent more favorable in a given year, agricultural productivity would increase 0.2 percent. Conversely, if weather was 1 percent less favorable, agricultural productivity would decline 0.2 percent. Adapting crops to weather and weather modification have great potential for increased productivity in agriculture. Accurate weather forecasts would contribute greatly. However, given the present state of knowledge, it is unlikely that such technological breakthroughs will occur by the year 2025.

FUTURE PRODUCTIVITY GROWTH

After establishing the quantitative relationship between agricultural productivity growth and its sources, we can simulate future productivity growth using the empirical model. However, both current and future research investment decisions will affect the path of productivity growth. Thus, we need a set of assumptions representing possible decisions that result in certain rates of R & E investment. We can than project the potential impact on productivity growth.

We consider the following five scenarios:

- No R & E--All public R & E expenditures will be cut off starting in 1980.
- Negative R & E growth--Public R & E expenditures are maintained at a -2 percent per year in real terms.
- Zero R & E growth--Public R & E expenditures are maintained at a zero growth rate, i.e., nominal increases in R & E just keep pace with inflation.
- Baseline--Real R & E growth is 3 percent per year, the same as during the 1929-72 period.
- High R & E growth--A 7-percent real R & E growth rate will accelerate research and development of new technologies and will increase extension activities for dissemination of the new technologies. As we anticipate that such an increase emphasis on R & E would make more new technologies available, we also evaluate the impact of possible unprecedented technologies on agricultural productivity.

For all scenarios, the farmers' educational attainment is assumed to increase along an S-shaped curve. Since 1939, the level of educational attainment of farmers has increased at an

increasing rate. However, it is not likely that this trend will continue indefinitely. There is a practical limit to how many years of education a farmer can undertake. It seems reasonable to assume that the level of educational attainment will eventually level off and approach a limit. It is hypothesized that the index of educational attainment will follow an S-shaped curve of the following form:

$$(2) \quad E_t = k/(1 + be^{-at})$$

where

E_t = the index of educational attainment of farmers in year t,

k = the upper limit of the education index,

a,b = parameters.

Assumed that the upper limit of the education index is the level at which all farmers have at least four years of post high school education. Fitting the education index data from 1939 to 1972 to the logarithmic form of equation (2) yields:

$$\hat{E}_t = 424/(1 + 3.682e^{-0.029t})$$

which was used to project the education index through the year 2025.

Although decision makers can exercise no control over weather, weather was included in the model as a stochastic variable. By including this variable, a stochastic simulation technique was used to project agricultural productivity growth based on the probability distribution of the weather index obtained from the measured weather index from 1900 to 1972. It appears that a normal distribution is a

good approximation to the frequency distribution. The parameters of the normal distribution were obtained from the measured weather index as follows: mean = 100.6 and the standard deviation = 11.4. These parameters were incorporated into the simulation routine and future values of the weather index were generated by the computer for all scenarios.

The projected education index and the alternative R & E growth rates were used to project future agricultural productivity. To simulate weather conditions for the 1980 to 2025 period, 200 values of the weather index were generated for each future year from the normal distribution to simulate future weather conditions. For each year, the mean, the standard deviation, and the range of the productivity index were computed. However, only the mean value of the productivity index is reported in this paper.

The Baseline Projection

The projected productivity index under the baseline scenario is shown in column 4 of table 1. The baseline scenario assumes that past R & E funding patterns will continue into the future. It is likely that the expected value of the productivity index will reach 148 in 2000 and 182 in 2025 with annual rates of increase of 1.1 percent for the 1978-2000 period and 0.8 percent for the 2000-2025 period. Although the limit to growth will not be reached by 2025, the long-term rate of productivity growth is declining.

Table 1.--Projections of U.S. Agricultural Productivity, 1980-25 (1967=100)

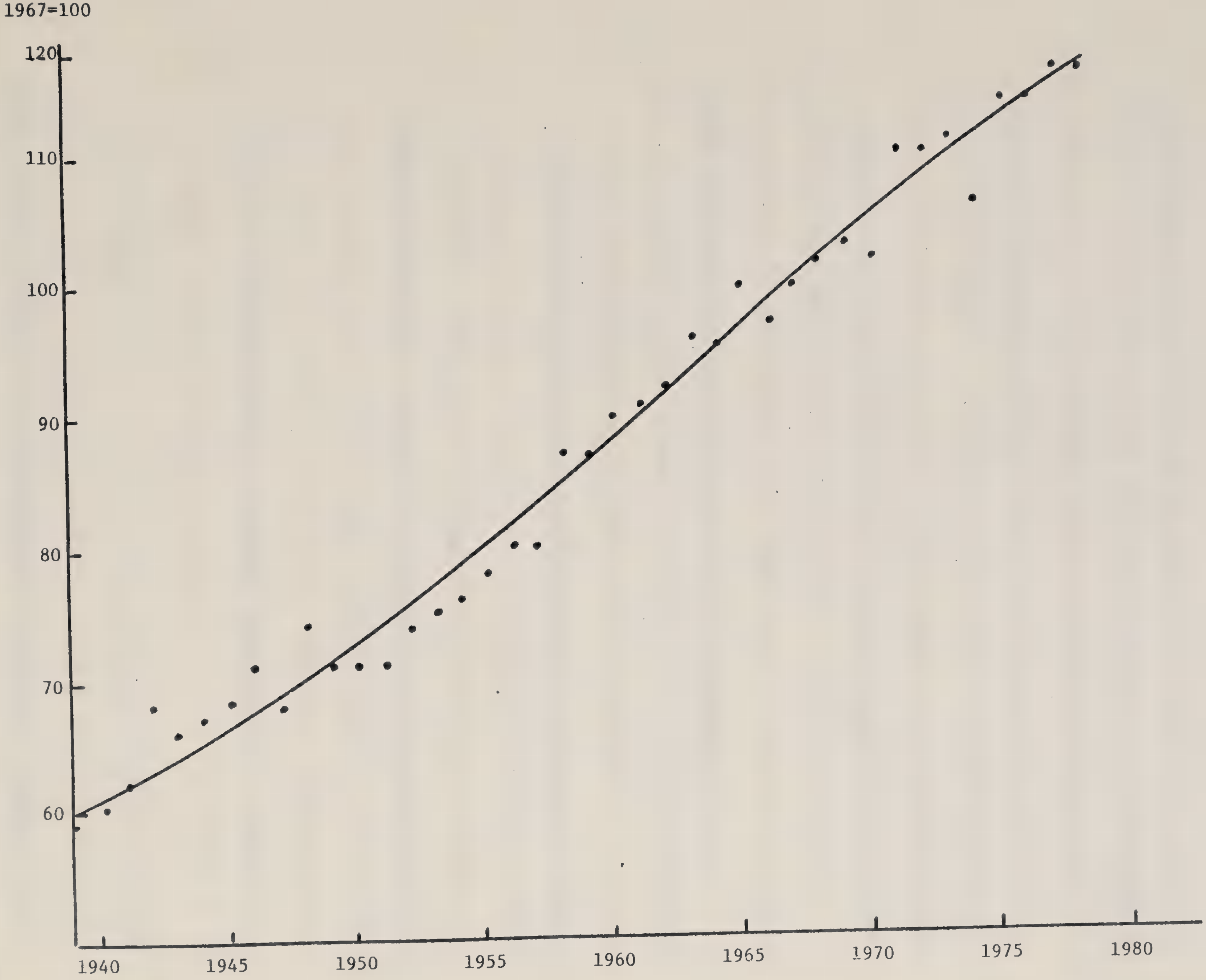
	Projected Productivity Indexes Under Alternative Scenarios				
	No R&E	Negative R&E	Zero R&E	Baseline	High R&E*
1978	117.0	117.0	117.0	117.0	117.0
1985	104.4	126.3	126.4	126.6	126.8
1990	87.9	132.6	133.0	133.7	134.5
1995	86.3	138.3	139.3	140.7	142.6
2000	90.1	144.0	145.5	147.8	150.8
2005	93.8	149.4	151.6	154.8	159.2
2010	97.6	154.6	157.6	161.8	167.5
2015	101.1	159.8	163.3	168.7	175.8
2020	104.5	164.6	168.9	175.3	184.1
2025	107.8	169.2	174.2	182.4	192.4

*This projection does not account for the impacts of emerging unprecedented technologies discussed later.

The reason for the declining rate of productivity growth over time is that currently productivity is growing along the growth curve of the science power epoch which began at the end of World War II. The rate of growth of the curve may have shown some signs of beginning to decline. As shown in Figure 2, productivity growth might have passed the inflection point and entered the era of diminishing growth rates. Several warning signals received around the country seem to support this observation.

For the last 20 years, average corn yields throughout the state of Iowa have been compared with yields from experimental farms run by Iowa State University where best technology has been used. In the late 1950's, the experimental farms produced twice as much corn as the average non-university farm. But now, this gap has nearly disappeared. Similarly, a Cornell University study of New York State predicts a leveling off in wheat production because plant breeders have raised yields about as far as is biological possible (Toth, 1979).

In observing the growth curves of carrying capacity of the farmer and his land in recent years, James G. Horsfall and Charles R. Frink of the Connecticut Agricultural Experiment Station conclude that the rapid expansion of the Nation's ability to produce more and more food seems to be over as demonstrated by the fact that growth curves that traced expansion over the years are flattening (Tameus, 1975). Glenn Salisbury, Director of the Illinois Agricultural Experiment Station, notes that local corn yields rose from 70 bushels an acre in 1955 to


1967=100
120
110
100
90
80
70
60
1940
1945
1950
1955
1960
1965
1970
1975
1980

130 bushels a decade later, but dropped toward 120 bushels in the last ten years. And after discussions with leading agricultural scientists, Victor McElheny concludes that the Nation may be living off past technological breakthroughs (Anderson, 1976). These observations suggest that applications of modern technology under the science power epoch may have been exhausted. Merely using more fertilizer, more pesticides and more efficient machinery may no longer mean higher productivity (Toth, 1979).

As indicated before, without new, unprecedented technologies, the rate of growth will decline. Since this scenario assumes that the public support for R & E increases at 3 percent per year, which is probably just enough to produce a series of minor technologies to stay on the current growth curve, no new unprecedented technologies are expected to emerge. Thus, the rate of productivity growth would decline under the scenario.

Recently, because of increasing public concerns about food safety, human nutrition, environment quality, and energy shortages, some of the R & E expenditures would have to be diverted to the development of "defensive" technologies in order to meet these new requirements. Thus, actual productivity growth could be smaller than projected above.

Effect of Reduced Funding

Reduced public support for R & E is one of the major concerns in agriculture, especially among farmers, agribusiness, agricultural

economists and scientists. In the recent Harvest Bowl conference at the University of Minnesota on shaping agriculture's future, the long-range impact of reduced funding for research and development in agriculture was one of the key issues discussed in the conference. Current (1967-80) data indicate that USDA funding of research and education programs increased at about 1 percent a year in real terms. State funds, having grown at a faster rate, bring the federal-state combined total real growth to about 2 percent per year, which is less than the rate of R & E growth assumed under the baseline scenario. 3/ For the purposes of this paper, a rate of R & E growth less than the rate assumed in the baseline scenario is referred to as reduced funding for R & E (in relation to the baseline scenario).

To estimate the long-range effect of reduced funding for R & E, productivity growth was projected under three R & E growth rates--zero percent, -2 percent, and no R & E. Under the zero R & E scenario, where public R & E expenditures are assumed to grow at a rate just offsetting the rate of inflation, the agricultural productivity index is expected to increase from 117 in 1978 to 146 in 2000 and to 174 in 2025 (Column 3, table 1). The rate of growth will decrease to 1.0 percent per year for the 1978-2000 period and 0.7 percent per year for the 2000-2025 period.

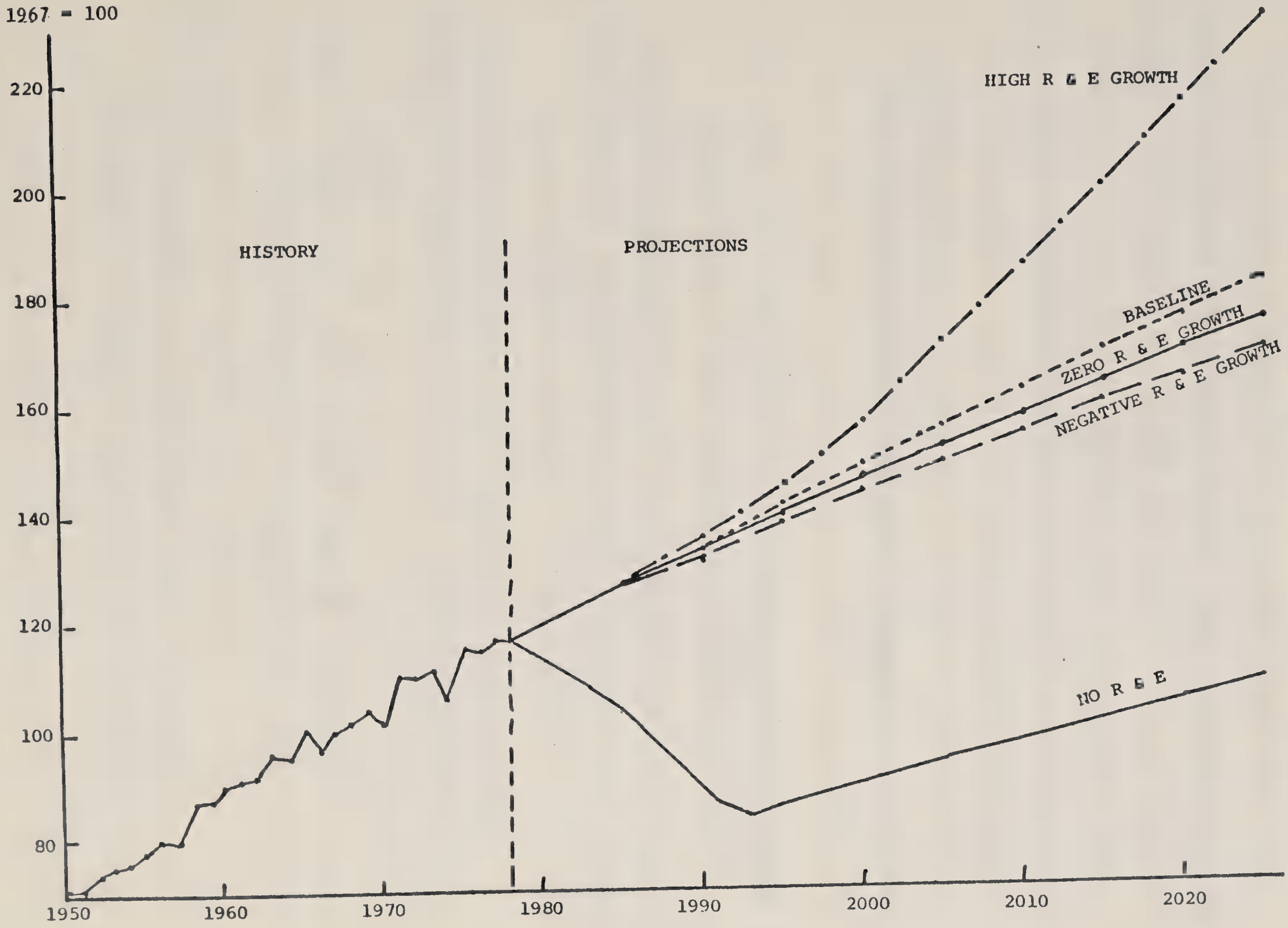
3/ The data for USDA funding of research and education programs were obtained from internal budget information and the state data were derived from the Current Research Information System.

With current inflation rate exceeding 10 percent a year, any nomial increase in R & E funding of less than the inflation rate will result in a negative rate of increase. Under the negative R & E growth scenario, which assumes that the real R & E expenditures will be reduced 2 percent per year starting in 1980, productivity will continue to increase but at a much slower rate as shown in column 2 of table 1. The productivity index is projected to increase from 117 in 1978 to 144 in 2000 and 169 in 2025. The annual rate of increase will be 0.9 percent from 1978 to 2000, and 0.6 percent from 2000 to 2025.

Because of long lags required to create a new technology, reduced funding for R & E has very little effect in the short-run, but it produces tremendous impact in agricultural productivity in the long-run. For example, the difference in the productivity index between the baseline and the negative R & E growth scenario is less than 1 index point in 1990. This difference widens as time elapes. In the year 2025, the difference in the productivity index between these two scenarios increases to 13 index points.

The effect of reduced funding for R & E can be dramatized by the no R & E scenario which cuts off all public R & E activities starting in 1980. The simulated results are shown in column 1 of table 1 and figure 3. Productivity will not plummet immediately due to the residual effects of previous investment in R & E. But it will decline rapidly, as shown in figure 3. Since the average length

Figure 3-Productivity Growth Under Alternative Scenarios



of the lag between investment in R & E and its ensuring effect on productivity is 13 years for U.S. agriculture, the productivity index will reach its minimum in 1993. Then productivity will increase gradually due to the increased level of educational attainment of farmers. Even though a few new technologies would be forthcoming, better educated farmers would be capable of fully utilizing the existing stock of technology to increase productivity. However, the productivity index will not be expected to return to the 1978 level by 2025.

TECHNOLOGICAL BREAKTHROUGHS

Past agricultural productivity growth has been examined, and future growth has been projected under the assumption that those forces which shaped past productivity growth will continue and that there will be no unprecedented technological breakthroughs.

Under the baseline scenario, agricultural productivity would continue to grow at about 1.1 percent per year through 2000, which is considerably less than the average annual growth rate of 1.6 percent over the past 50 years (1928 to 1978). Although the limit to growth would not be reduced by the turn of the century under this scenario, the growth rate would decline. To prevent this situation from occurring, more investment in agricultural R & E is needed to accelerate the development of new technologies and to facilitate their adoption by farmers.

Under the high R & E scenario, public investment in R & E is assumed to increase at 7 percent annually. With greater support for research, it is likely that more technologies will become available for adoption. It is assumed that if any new, potentially unprecedented technologies emerge, they will be developed and adopted by farmers under this scenario, thereby shifting productivity growth to a new S-shaped curve.

Will there be technological breakthroughs in agriculture by the year 2025? What new agricultural technologies are being explored by scientists? Which technologies will have marked impacts on agricultural production? What is the probability of a particular technnology's becoming available for commercial adoption by a specific year? What will be its adoption profile? What is the extent of the new technology's impact on crop and livestock production? To answer these questions, we conducted a study in 1974 in cooperation with Resources for the Future and the Ford Foundation. Existing literature on emerging technologies was reviewed, and researchers in the Agricultural Research Service, the Cooperative State Research Service, and the Extension Service--all now part of the Science and Education Administration (SEA)--were interviewed using modified Delphi and relevance-tree methods.

The literature review yielded an excellent study by Wittwar (1978), who presented 10 future technologies which are on the scientific frontiers. These 10 technologies were included in the questionnaries and subsequent interviews with agricultural scientists confirmed most of them.

Emerging Technologies

Scientists we interviewed identified the following 12 emerging technologies as having significant impact potential for agricultural productivity (Cline 1974). Most of these technologies were also identified by the National Academy of Sciences (1975) study as being on the scientific frontiers.

1. Enhancement of photosynthetic efficiency: Improving the process by which living plants form carbohydrates through genetic selection, physical modification, and chemical modification; enhancing the biological capacity of living plants to absorb nitrogen for protein synthesizing; and enhancing plant growth through elevating atmospheric levels of carbon diodixe.
2. Water and fertilizer management: Increasing efficiency of inputs used in production through combined water and fertilizer management systems such as that developed for potatoes in Washington, expanded trickle or drip irrigation, new subirrigation techniques, and foliar fertilizer application.
3. Crop pest control strategies: Adopting total pest management systems that incorporate resistant varieties, sex attractants, juvenile hormone analogs, and other biological controls which reduce energy inputs, environmental hazards, and pest control costs.

4. Controlled environment or greenhouse agriculture: Using plastic or glass covers over plants with or without the addition of heat and carbon dioxide--likely restricted to high-value and specialty crops.
5. Multiple and intensive cropping: Double cropping and intensive cropping to increase per acre yields.
6. Reduced tillage: Expanding use of minimum or reduced tillage techniques, a process minimizing the number of times farmers must cultivate a given field.
7. Bioregulators: Using certain natural and synthetic compounds to regulate the ripening and senescence of horticultural products. When applied at the pre-harvest stage, they can enhance ripening and facilitate mechanical harvesting. When applied after harvest, they can slow life processes and prolong shelf life of some fruits and vegetables and reduce cooling costs.
8. New crops: Developing new and improved hybrids and searching for alternate food crops.
9. Bioprocessing: Extending traditional agricultural production so that unpalatable raw products, such as cellulose and petroleum materials, can be converted into edible protein, carbohydrates, and fats to provide additional animal feed sources.

10. Antitranspirants: Inhibiting plants' tendency to lose water through evaporation.

11. Developing plants to withstand drought and salinity: Developing plants which genetically resist drought better and thrive on saline water.

12. Twinning: Enhancing multiple births in beef cattle through breeding and selection of livestock for twinning genetic traits, multiple ovulation through hormonal control, and embryo transfer.

Most researchers believe that many of these emerging technologies will be required to maintain present productivity growth in the face of new constraints. As a result, the impacts of these technologies have already been captured in our base projections. Only three technologies--twinning in beef cattle, bioregulators, and photosynthesis enhancement--are considered to have the potential for unprecedented impacts on agricultural productivity; therefore, their impacts are included in the high R & E scenario.

A recent study by the Office of Technology Assessment (1977) partly confirmed the potential of these three technologies. A panel of scientists representing agricultural and nonagricultural interests, private research organizations, and industries identified three areas of basic research providing great opportunity for fundamental scientific discoveries. These areas are photosynthesis, nitrogen fixation, and genetic engineering for plants. We also identified the

first two areas as having the potential for unprecedented impacts on agricultural productivity. Because photosynthesis and nitrogen fixation are closely related, we combined them into a single technology--photosynthesis enhancement.

Impact Analysis

To estimate the impacts of these three emerging technologies on agricultural productivity, we obtained the following information for each technology:

1. The subjective probability distribution: the probability of the occurrence of each new technology in year t (q_t), were t = 1, 2, ..., n; and the year 1 denotes the first year of projections.
2. The adoption profile; the percentage of crop or livestock output affected by the new technology in the ith year of adoption (a_i), where i = 1, 2, ..., n.
3. The specific crops or livestock affected by the impacts.
4. Increases in productivity of the affected crops or livestock, measured by the ratio of increased output to increased inputs in constant dollar values, given adoption of the new technology (f).
5. Output of affected crops or livestock as a percentage of the total output (r).

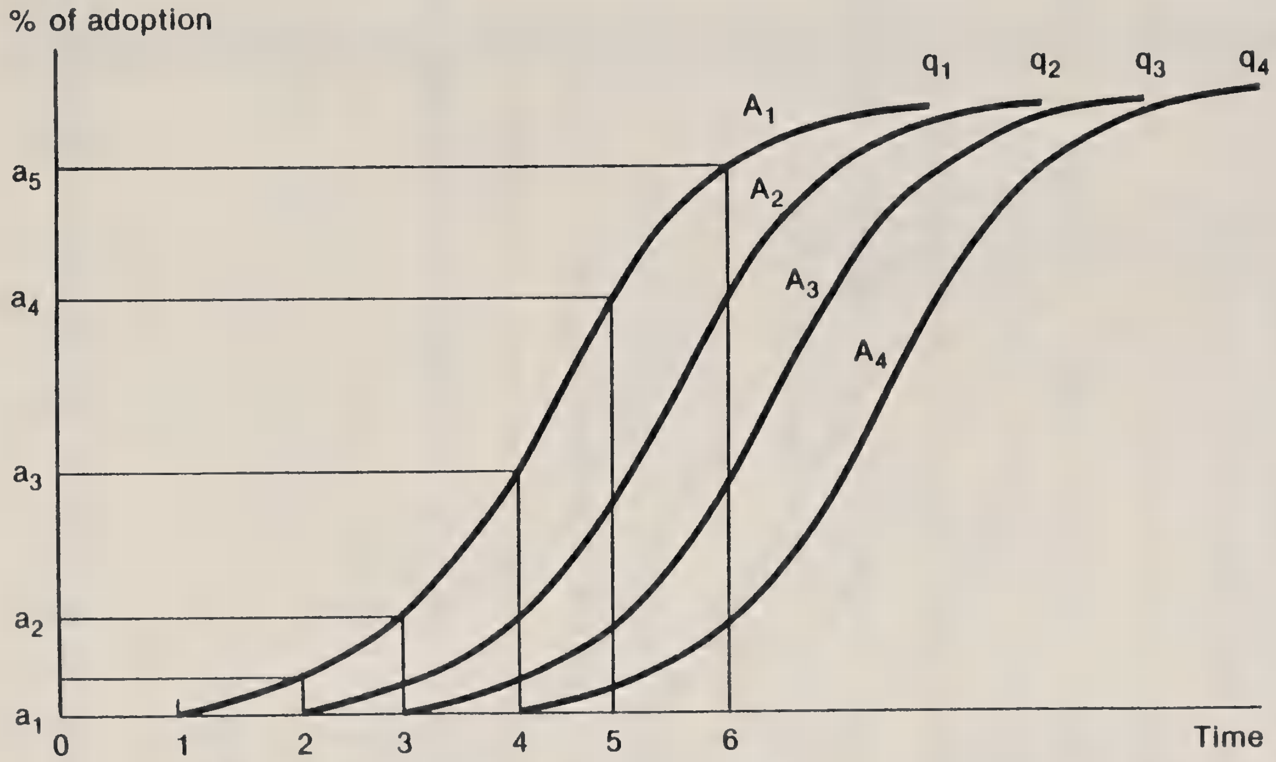
Adoption profiles vary among different technologies. The length of time from introduction to the point that adoption reaches its maximum ranges from about 35 years for twinning in beef cattle production to over 50 years for photosynthesis enhancement. For each technology, this adoption rate is expected to be slow at the initial stage. As more farmers are attracted to the new technology, this rate is expected to increase exponentially. Then the rate of increase will decline, and the percentage of adoption will gradually approach a ceiling as a saturation point is reached.

As shown in figure 4, after the first year of commercial introduction, the percentage of adoption is a_1; after the second year, a_2; the third year, a_3; and so forth. It is also assumed that the adoption profile will remain the same regardless of when the technology becomes commercially available. The adoption curve A_1 refers to the adoption profile when the technology is introduced in year 1; A_2, the adoption profile for year 2; and A_3, for year 3; and so forth.

Let us assume that the jth technology is introduced for commercial adoption in the year t. If fully adopted, it will increase productivity of the affected commodities f_j percent. In year k, that is, k-t after commercial introduction, adoption of the jth technology will increase productivity of the affected commodities $a_{k-t}\ f_j$ percent. Let us assume further that the affected commodities constitute r_j percent of the total output; then, the impact on the jth technology on productivity of the total farm sector in

Figure 4

Profile of Technology Adoption by Farmers



the year k is: $I_{kj} = a_{k-t}\ r_j f_j$

where t denotes the year of commercial introduction.

The above equation denotes the impact on agricultural productivity when the jth technology is actually introduced in year t. However, we do not know with certainty that any particular technology will be introduced in a specific year. Only the subjective probability distribution of occurrence for each new technology in year t can be determined. To illustrate, let us consider the simplified case in figure 5. In year 5 (k = 5), technology introduced in years 1 through 4 only will have an impact. If the technology is introduced in year 1 (t = 1), the impact in year 5 will be the impact in the fourth year of adoption (k-t = 5- 1 = 4) I_4. If the technology is introduced in year 2, the impact in year 5 will be I_3. Likewise, the impacts of the technology introduced in years 3 and 4 will be I_2 and I_1, respectively. As the probability that the technology will be introduced in year 1 is q_1, in year 2 is q_2, in year 3 is q_3, and year 4 is q_4, the expected value of the impacts of the technology in year 5 is:

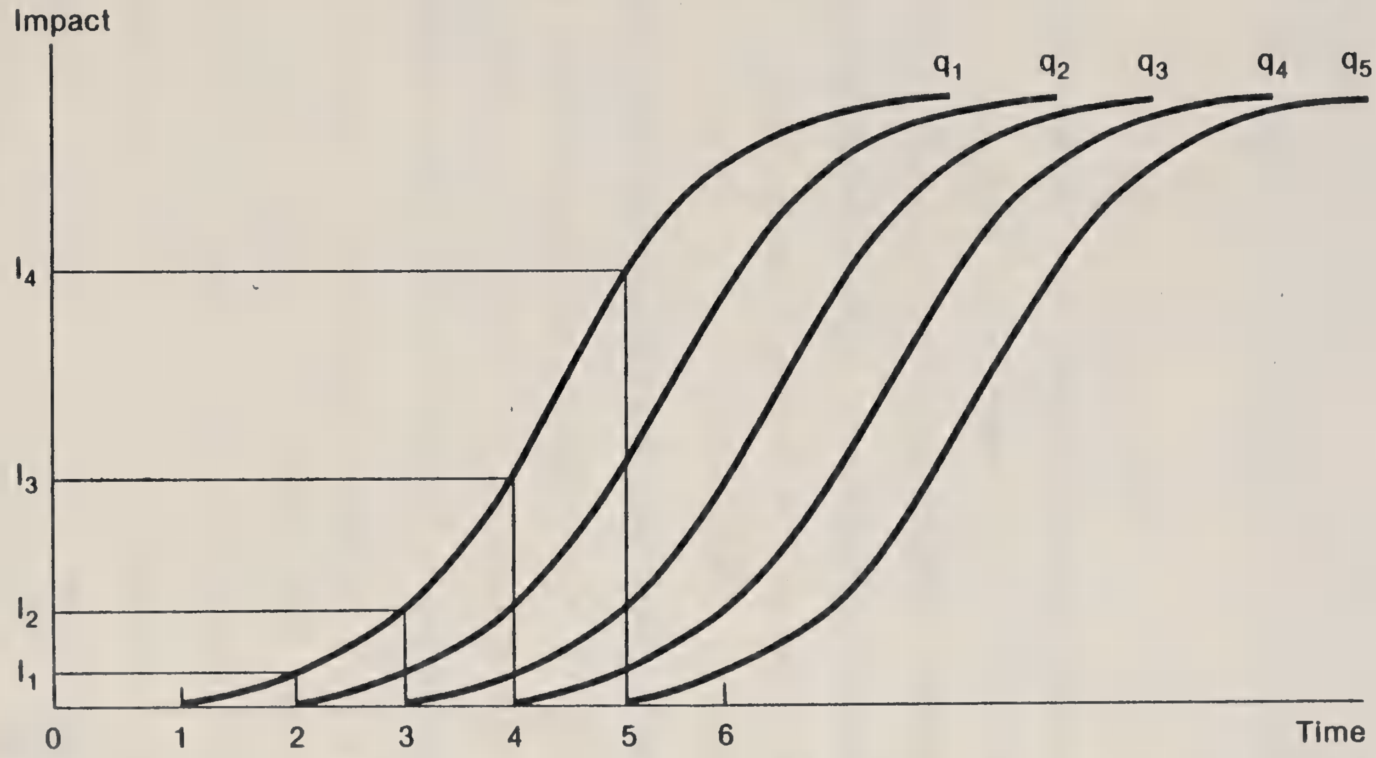
$$x_5 = q_1 I_4 + q_2 I_3 + q_3 I_2 + q_4 I_1$$

Generally the expected value of the impacts of the jth technology in the kth year is:

$$X_{kj} = \sum_{t=1}^{k-1} q_{tj}\ I_{kj}$$

Figure 5

Impact of New Technology on Agricultural Productivity



Let us further assume that the impacts of the three technologies are additive. The total expected increase in productivity due to the adoption of the three technologies in year k can be obtained by:

$$X_{k.} = \sum_{j=1}^{3} X_{kj} = \sum_{j=1}^{3} \sum_{t=1}^{k-1} q_{tj} I_{kj}$$

The estimated impacts of these three technologies on productivity projections are incorporated in the high R & E scenario.

Expected productivity growth incorporating the effect of adopting twinning, bioregulators, photosynthesis enhancement, and the combination of all three technologies are listed in columns 1 through 4 of table 2.

For the year 2000, the productivity index's expected values under the high R & E scenario are boosted to 152, 155, and 151 due to twinning, bioregulators, and photosynthesis enhancement, respectively and to 156.0 due to the effect of all three technologies. The annual rate of productivity growth is 1.3 percent.

Because most of these technologies would not be ready for adoption commercially until the 1990's and it takes decades to complete the adoption process, their expected impacts on agricultural productivity growth rate of 1.3 percent per year toward 2000 is still less than the historical rate of 1.6 percent for the past 50 years. However, if we project to the year 2025 under this scenario to allow more time for widespread adoption, productivity would be expected to grow an average of 1.6 percent per year from 2000 to 2025. This is the same rate as during the past 50 years.

Table 2.--Impacts of Emerging Technologies on Agricultural Productivity Under the High R & E Scenario (1967=100)

	Expected Values of Productivity Index Adjusted for Impacts of			
	Twinning	Bioregulators	Photosynthesis Enhancement	All Three Technologies
1978	117.0	117.0	117.0	117.0
1985	126.8	126.9	126.8	126.9
1990	134.5	135.1	134.5	135.1
1995	142.7	144.4	142.7	144.6
2000	152.2	154.5	151.2	156.3
2005	163.9	164.6	160.5	170.6
2010	175.9	174.1	170.2	185.2
2015	187.0	183.0	181.0	199.4
2020	197.2	191.8	193.2	214.0
2025	206.9	200.7	206.9	229.7

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